

DEVELOPMENT OF A LONG-TERM ECOLOGICAL MONITORING PROGRAM IN
DENALI NATIONAL PARK AND PRESERVE, ALASKA (USA)¹

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Abstract.--A Long-term Ecological Monitoring (LTEM) program began at Denali National Park and Preserve, Alaska (USA) in 1992, as a prototype for subarctic parks. The early history of the Denali LTEM program provides insight into the challenges that can arise during monitoring program development. The Denali program has thus far taken a watershed approach, involving collocation of study effort for a mix of abiotic and biotic attributes within a small, headwater stream (Rock Creek) which crosses the tundra-taiga boundary. An initial effort at integration and synthesis of meteorological, vegetation, small mammal and passerine bird data for the first 7 years of the program found few correlations, but power was low. We will now attempt to balance the intensive work in Rock Creek by developing a cost-effective sampling design that includes more of the park. We are also working to improve linkages between the monitoring program and park management decision-making and to strengthen data management and reporting mechanisms.

¹ Paper presented at symposium, Toward a Unified Framework for Inventorying and Monitoring Forest Ecosystem Resources: Guadalajara, Mexico, November 1-6, 1998.

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INTRODUCTION

In 1992, the National Park Service (NPS) began to develop prototype, long-term ecological monitoring (LTEM) programs in selected parks representing major biogeographic regions within the United States. Denali National Park and Preserve (Alaska, Fig. 1), one of the first four parks in the program, was chosen as the testing ground for Alaska parks. Alaska has 23 national parks, covering 21.5 million ha. These parks represent 66% of the total land base of the U.S. national park system. Thus, lessons learned developing the Denali LTEM program could influence how monitoring is done over a significant proportion of U.S. park lands. Like Denali (2.4 million ha), the Alaska parks encompass vast, roadless areas, and access is a major constraint on park management, including monitoring.

Denali National Park and Preserve includes Mount McKinley (6,194 m)--the tallest mountain in North America. Its huge massif is highly glaciated, and 17% of the park is covered with glaciers. The surrounding park lands are ecotonal between alpine tundra and taiga. Denali receives over 350,000 visitors each summer and is one of the prime tourist destinations within the state. The main attraction (besides the mountain itself) is charismatic wildlife [e.g., grizzly bears (*Ursus arctos*), Dall sheep (*Ovis dalli*), wolves (*Canis lupus*)], seen from park buses traversing a 144-km gravel road into the park.

The NPS and U.S. Geological Survey (USGS), working as partners, are developing the Denali LTEM program. Scientists from the University of Alaska Fairbanks and ornithologists with two nonprofit organizations, the Alaska Bird Observatory and the Institute for Bird Populations, are also involved. The Denali LTEM program currently includes monitoring a broad array of attributes, including air and water quality, meteorology, soils, glaciers, fire, and bird (passerine and raptors), and mammal (charismatic and otherwise) populations. We report here on

a major aspect of the monitoring program which has involved the use of a watershed approach to organize study effort for a mix of abiotic and biotic attributes within a single watershed, Rock Creek (Thorsteinson and Taylor 1997). Linkage of intensive studies within a watershed is expected to yield information about ecosystem relationships, a primary goal of the Denali LTEM program. The Rock Creek studies include collection of the typical data sets associated with watershed studies (e.g., atmospheric deposition, water chemistry), but also include collection of data on small mammal and bird populations.

In this paper, we have two thrusts. First, we discuss the manner in which the Denali LTEM program has been implemented and explain some of the challenges encountered. We then focus on a different aspect of the Denali story by presenting an analysis and synthesis of the 7-year dataset for Rock Creek, in an attempt to find relationships between abiotic factors (meteorology), vegetation, and vertebrate populations (small mammals and passerine birds).

EARLY HISTORY OF THE LONG-TERM ECOLOGICAL MONITORING PROGRAM AT DENALI

The original proposal for the Denali LTEM program was written in late 1991. The proposal was written quickly, in response to a national *Call for Proposals* deadline with a short lead time. The proposal outlined a general scheme of monitoring that would concentrate on underlying components of the ecosystem. The proposal also outlined a study design based on watersheds. The park was divided into 5 major watersheds. The authors proposed to link studies of birds, small mammals and vegetation, set against a backdrop of meteorological, soil, water

and aquatic invertebrate studies. The program would start in one watershed, and eventually, with additional funding, expand to include the other 4 watersheds.

The idea of using watersheds as the basis for monitoring terrestrial ecosystems in Alaska parks originated at a NPS workshop held in 1989 (Peale et al. 1993). This conference included several presentations on existing programs organized around watersheds, including Hubbard Brook, the *sine qua non* of watershed studies. A follow-up report to the workshop further developed the watershed theme. The idea was espoused that NPS monitoring in Alaska should go beyond population monitoring of the charismatic megafauna and look at the broader ecosystem in an integrated fashion. Watersheds were advocated as a way to stratify the enormous territory of Alaska parks into ecologically meaningful units of manageable size.

The Denali proposal was successful, and just a few months after penning the proposal, park staff were faced with implementing it. The park moved immediately into the collection of data. Only partial funding was received in the initial year, which heavily influenced the selection of Rock Creek as the primary study site. The proposal had called for starting the LTEM program in the McKinley River watershed located near the end of the park road. As the field season drew near, park managers realized they could not afford to start work at such a remote location. They turned to Rock Creek, a small creek adjacent to park headquarters. The idea was to use Rock Creek as a place to quickly and cheaply test methodologies prior to implementation elsewhere in the park. However, the idea of using Rock Creek as a testing ground faded over the years as the Rock Creek work took on a life of its own.

In the early years of the Denali LTEM program, the funding and responsibility for program development was split between the park and other entities. At first, the split was between the park and the Alaska regional office of the NPS. Later, the split was between the park

and the National Biological Service (NBS). The split responsibility for program development, involving personnel spread across organizations and duty stations, required the establishment of solid mechanisms for communication and coordination. The need for such mechanisms was not recognized immediately, and took several years to develop.

Another challenge arose during the course of the program's development as park staff began to realize the form that the monitoring program was taking. Rock Creek is on the eastern boundary of the park, and conditions in Rock Creek appeared to bear little relation to conditions in the rest of the park. The watershed approach, with its apparent focus on biogeochemical cycles, was considered esoteric, with little relation to park management issues. Reporting from the LTEM program was also minimal. Although study sites for various attributes were collocated within Rock Creek, no mechanisms were in place for the integration or sharing of data. These factors conspired to create a general aura of dissatisfaction with the LTEM program.

A national review of the Denali program in 1995 was also critical, especially of the decision to concentrate the monitoring effort in a single watershed. The park was directed to develop a clearer statement of objectives and to modify the conceptual design accordingly. In response, the park led an effort to move the monitoring program in the direction of providing information useful for management. In 1996, 2 workshops were held to identify likely anthropogenic and natural stressors to the Denali ecosystem, following Noon et al. (1998). The ecological consequences of the stressors acting on the Denali ecosystem would guide selection of the attributes to be monitored, at a variety of scales and organizational levels (i.e., landscape, community, population, individual, genetic).

The park is currently working closely with the USGS, Biological Resources Division (formerly the NBS) in writing a new conceptual plan for the LTEM program. The current focus

of this joint planning effort is on improving linkages between the monitoring program and park management decision-making, broadening the geographic scope of the LTEM program, and improving data management and reporting.

INTEGRATION OF MONITORING DATA: CORRELATES OF SMALL MAMMAL AND PASSERINE BIRD ABUNDANCE

Despite some of the difficulties in the early days of the Denali LTEM program, work continued in Rock Creek according to the original design. Thus, we now have 7 years of experience and data within the watershed on which we can begin to report. The intent of this exploratory synthesis is to examine fluctuations in several monitored components of the Rock Creek watershed. One of the themes of the LTEM program is to document the range of variation in measured attributes of the system. Our objective in the integration exercise is to determine possible causal mechanisms that could give rise to these variations. We chose to look first at inter-annual patterns in small mammal abundance and passerine bird abundance and productivity within Rock Creek. Were there meaningful similarities between vole abundance and bird abundance and productivity and some of the biotic and abiotic factors around them?

Methods

Small mammal and passerine bird populations

For small mammals, we used abundance estimates from the final sampling occasion of the field season, typically the first week of September, when abundance is at its annual maximum and estimates are the most reliable (see Rexstad 1994 for methodology). Data were from a single trapping grid in spruce forest, known as RF1. We computed abundance estimates

(animals/ha) for the tundra vole (*Microtus oeconomus*) and red-backed vole (*Clethrionomys rutilus*) from 1992-1998.

Data on passerine birds in Rock Creek came from 2 separate monitoring efforts: (1) 4 point count transects with a total of 48 stations (Paton 1996) and (2) 3 constant-effort mist netting stations (DeSante 1997). The point count data provided 1 measure of population abundance: an annual Frequency of Occurrence (FO). The FO for a particular species was the proportion of point count stations where that species was observed in a given year based on several visits during the breeding season. The mist netting data, collected under auspices of the Monitoring Avian Productivity and Survivorship (MAPS) program (DeSante et al. 1995), provided measures of abundance and productivity. Capture rates for adults and young for the three mist net stations combined were calculated for constant efforts of 600 net-hours, to provide a measure of abundance based on catch-per-unit-effort (CPUE). The proportion of the constant effort catch that was young birds was used as a measure of productivity.

In our analyses of bird populations, we focused on species that occurred in sufficient abundance for point counts to accurately reflect annual fluctuations, i.e., those with a FO of 14% or greater (Paton 1996, Paton and Pogson 1996). These species were aggregated into guilds based upon their migratory strategy (Hayes 1995). *Permanent residents* remain near the Park boundaries throughout the year [gray jay (*Perisoreus canadensis*)], *irruptive migrants* are restricted to migration within Alaska [redpoll (*Carduelis* spp.)], *neararctic migrants* have ranges that extend beyond Alaska's borders [dark-eyed junco (*Junco hyemalis*) and varied thrush (*Ixoreus naevius*)], *short-distance neotropical migrants* remain north of South America [American robin (*Turdus migratorius*), orange-crowned warbler (*Vermivora celata*), white-crowned sparrow (*Zonotrichia leucophrys*), Wilson's warbler (*Wilsonia pusilla*) and yellow-

rumped warbler (*Dendroica coronata*)], and *long-distant neotropical migrants* winter in South America [Swainson's thrush (*Catharus ustulatus*)].

Potential Correlates

As potential correlates, we computed annual summary statistics of data from the meteorological and vegetation studies within Rock Creek (Tables 1, 2). We also used several correlates from the bird studies as possible correlates of small mammal populations (and vice versa). Not all Denali LTEM projects were initiated at the same time, hence, data were not available for every attribute in each year (Table 1). All correlations tested the null hypothesis that $\rho = 0$. In these exploratory tests, we set $\alpha = 0.10$ to determine significance.

Three weather indices were calculated from meteorological data collected at park headquarters in the lower part of the Rock Creek drainage. These indices were a *Winter Severity Index*, calculated from the perspective of voles, and a *Spring Onset Index* and a *Spring Rainfall Index*, which we thought could be important to both voles and birds.

Winter Severity Index.--Because of their small size, voles are susceptible to low temperatures and can suffer high rates of mortality during extreme winter conditions. Temperatures experienced by voles in the subnivean environment can be moderated by an insulative snow layer that affords them protection from the worst of an arctic winter (Marchand 1982). Maximum buffering is achieved at snow depths of approximately 35 cm or greater. We defined the winter severity index for voles as a measure to incorporate daily minimum air temperature and snow depth.

The vole winter severity index (WSI) was defined as

$$WSI = \sum_{d \in \Delta} \max(0 - T_d, 0) \times \max(1 - S_d/35, 0) \quad (1)$$

where Δ = the set of Julian dates used in the index, T_d = the minimum air temperature in degrees Celsius on day d , and S_d = the snow depth in centimeters on day d . When either $T_d \geq 0^\circ\text{C}$ or $S_d \geq 35$ cm, the daily contribution to the index is zero. When $T_d < 0^\circ\text{C}$, the unweighted daily contribution is the difference between 0°C and T_d . This value is then weighted by the amount of snow on the ground, ranging from a weight of 0 (≥ 35 cm) to a weight of 1 (0 cm). For a day with a minimum air temperature of -7°C and 5 cm of snow on the ground, its unweighted contribution to the index is 7, which, when multiplied by its weight of $1 - 5/35$, gives a weighted contribution of 6. For any given year, the daily values were summed across all days from 1 September of the previous year to 31 May of the current year to yield the WSI. With this definition, a larger index indicates a harder winter for voles.

Spring Onset Index.-- Much biological activity in the arctic is constrained to a short period in the summer. The duration of summer impacts the productivity of plants and animals alike. We defined the spring onset index (SOI) as a measure involving daily mean air temperature that allowed an objective determination of the arrival of spring at Denali National Park and Preserve headquarters. It is a cumulative degree-day index that sums the degrees the mean daily temperature is above 5°C and reports the Julian date that this measure first exceeds 50. A larger spring onset index indicates a later spring.

Spring Rainfall Index.--With a late spring, the ground remains saturated longer, delaying the rise in small mammal population abundance. Similarly, this delay can be caused by excessive

precipitation, which can reduce bird productivity. We defined the spring rainfall index (SRI) as the cumulative rainfall in centimeters during the months of May and June.

The vegetation correlates we considered included two measures from monitoring studies of white spruce (*Picea glauca*), the dominant forest tree throughout forested regions within Denali park. These measures were annual cone counts and annual seed counts. The other vegetation measures included were from studies of annual berry production for three important berry-producing species: crowberry (*Empetrum nigrum*), blueberry (*Vaccinium uliginosum*) and cranberry (*Vaccinium vitis-idaea*).

Because such a large number of bird species was monitored, but relatively few species were present in numbers that allowed meaningful comparison, we calculated summary measures on 2 groups based on the point counts: a “Best 5” group and a “Best 10” group. The ‘Best 5’ species were identified as the 5 species with the largest FOs over all years. These species were American robin, dark-eyed junco, Swainson’s thrush, varied thrush, and white-crowned sparrow. The ‘Best 10’ species included these 5 species plus gray jay, orange-crowned warbler, redpoll, Wilson’s warbler, and yellow-rumped warbler. The mean FOs used were the mean FO of these 5 or 10 species for each year. Similarly, we used these groups with the mist-netting data to calculate mean CPUE and mean productivity.

As a measure of avian diversity in Denali National Park and Preserve, we calculated 2 measures of species richness from point count and MAPS data. Each richness measure was the total number of avian species identified annually by the respective program.

Results

Microtus and *Clethrionomys* abundance levels for 1992-1998 (Fig. 2) showed large inter-annual fluctuations with no correlation between them ($R=0.43$, $P=0.33$). Correlations and significance levels were then computed separately for each species (Table 3). *Microtus* abundance was correlated to WSI ($P=0.02$). *Clethrionomys* abundance was correlated to avian species richness (MAPS) ($P=0.04$) and was marginally related to Avian CPUE (Best 5) ($P=0.10$). Small mammal abundance was not significantly correlated with any of the other measures considered.

Passerine bird abundance and productivity for the various migratory guilds were correlated with a few of the measures considered (Tables 4, 5, and 6). For example, permanent resident frequency of observation was marginally correlated with cone count ($P=0.07$), point count richness ($P=0.06$), and crowberry count ($P=0.10$). Permanent resident productivity was correlated with winter severity ($P=0.05$) and marginally correlated with avian productivity (Best 5) ($P=0.07$). Permanent resident CPUE showed no correlation with any of the measures. Most significant correlations ($P\leq 0.05$) over all guilds were found with frequency of observation (6), compared to productivity (2) and CPUE (4).

DISCUSSION

The correlation analysis revealed few measures with a statistically significant correlation with small mammal abundance. However, several measures with a large positive or negative correlation could be significant with larger sample sizes. In addition, this correlation analysis only considers a single correlate at a time. Small mammal abundance is unlikely to be driven by

one biotic or abiotic factor. Two factors that individually have little correlation with abundance may together go far in explaining causal mechanisms.

With our current sample sizes of 4 to 7 years, we may not yet have the power to detect relationships. We ran power simulations to determine how many more years of data might be required to detect significant univariate relationships, given the levels of variation observed thus far. With a true correlation of 0.5 and sample sizes from 4 to 7, power to detect a significant relationship at the 0.05 level ranges from less than 0.1 to 0.2. To attain power of 0.8, we need a sample size of around 10 when the true correlation is 0.8 and a sample size of around 30 when the true correlation is 0.5. Thus, for even highly correlated variables, we need to continue collecting data for another few years before we can determine whether these seemingly nonsignificant relationships are truly nonsignificant or the result of small sample sizes.

The correlation of WSI with *Microtus* abundance may have biological significance. This relationship provides the beginning of a conceptual model against which future monitoring data can be compared (i.e., cold winters with little snow may impact *Microtus* populations). Having an expected value against which annual monitoring data can be compared helps build our understanding, and at the same time, makes us more diligent about exercising the data on a regular basis. Both are important ingredients for success in long-term monitoring programs.

Our synthesis efforts for understanding passerine dynamics are clearly just beginning. The issue is complicated by the dual monitoring efforts of point count transects (Paton 1996) and MAPS constant-effort mist nets (DeSante 1997) as well as the proliferation of species monitored. Avian population dynamics are additionally confounded with migratory patterns over varying distances. Given the differences in correlations between migratory bird guilds, we suggest future analyses be done with similar groupings. With only local data as covariates, we may ultimately

only be able to understand factors affecting year-round residents of Denali National Park and Preserve.

This exploratory integration exercise with the Rock Creek small mammal, avian, weather and vegetation data sets demonstrates the challenges in using the monitoring program to provide information that improves our understanding of ecosystems. Clearly, much longer term and more extensive data will be necessary to reveal the true nature of the ecological relationships. Maintaining a data collection program such as this can be difficult when it takes so long to reveal trends or relationships.

The lack of probability-based sampling procedures in Rock Creek is an important limitation, because we cannot make inferences to the rest of the park. To monitor resources in a park the size of Denali, the intensive effort in Rock Creek must be balanced by more extensive, probability-based sampling, and by use of such tools as remote sensing. In the next phase of the program's development, we plan to explore cost-effective sampling designs that include the whole park.

Two lessons about monitoring program development emerge from the Denali experience thus far. The first is to clearly define the roles of the managers, investigators, and technicians involved in the monitoring program and develop good lines of communication. The second lesson is to not be too hurried.

From the beginning, the Denali LTEM program involved a mix of personnel. The participants represented different scientific disciplines. They hailed from different parts of the NPS organizational structure, from outside the NPS, and from different parts of Alaska and other states. The roles and responsibilities of each participant were not clearly defined. Without day-to-day contact between the participants, communication about the program and its direction was

difficult. By their nature, ecological monitoring programs involve a variety of participants. Recognizing from the outset that monitoring programs are a team effort will help engender success. Teamwork and communications must be budgeted for and integrated into the program in the same way as data management and quality assurance/quality control.

The drawback of being too rushed at the beginning of a program is the second lesson from Denali. The Denali LTEM program was born seemingly overnight. The time between approval of the proposal and the beginning of work was compressed to months. There was no interim period of attribute selection, study plan development, or review to refine the ideas in the proposal. This rush to the field had important consequences. The goals and objectives for the program were not solidified and documented. Reviews by statisticians and potential data users did not occur. Important choices were made, such as selection of watersheds as the sample unit and selection of Rock Creek as the primary study site.

The consequences of using the watershed approach were not fully recognized until the program had been underway for a few years. Watersheds are attractive study areas for a number of purposes, but especially for studies of ecosystem processes (Slaughter et al. 1995). Understanding ecosystem processes is one goal of the Denali LTEM program, but the program also intends to provide information for management decision-making. The watershed design is unlikely to provide the park with that type of information. Thus, the park must now reconsider its allocation of monitoring effort to address this other important need. The Denali experience reinforces the importance of clearly envisioning intended data uses before any data are collected and carefully matching the design to the objectives (Overton and Stehman 1995, Soballe 1997, Whitfield 1988, Ward et al. 1986).

ACKNOWLEDGMENTS

The work we report on here has involved many researchers, technicians and volunteers. We greatly appreciate the continued patience and support of the many NPS personnel involved in the development of the Denali LTEM program, especially G. Olson, J. Van Horn, P. Brease, K. Karle, J. Roush, and A. Blakesley. We specifically thank Jon Paynter and Carl Roland, NPS, for providing data used in this synthesis. Our account of the program's history relied heavily on notes compiled by T. Smith (USGS) during his tenure with the program (1997). This manuscript was greatly improved by reviews of T. McDonough, L. Holland-Bartels, P. Geissler, and 1 anonymous reviewer.

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Table 1. Time-sequence of attribute data from the long-term ecological monitoring program available for synthesis, Rock Creek Watershed, Denali National Park and Preserve, Alaska.

Attribute	1992	1993	1994	1995	1996	1997	1998
Meteorology ¹	x	x	x	x	x	x	x
Vegetation							
<i>Picea glauca</i> cone count ²	x	x	x	x	x	x	
<i>Picea glauca</i> seed count ³		x	x	x	x	x	
Berry count ⁴			x	x	x	x	
Passerine Birds							
Point counts ⁵		x	x	x	x	x	
Constant-effort mist netting ⁶	x	x	x	x	x	x	
Small Mammals ⁷	x	x	x	x	x	x	x

¹ Data collected at National Weather Service station located at Denali National Park and Preserve Headquarters since 1925. Includes daily minimum and maximum temperatures, precipitation and snow depth.

² Number of cones on marked trees (5 per plot) in 3 forested plots in Rock Creek Watershed.

³ Number of seeds captured in 6 seed traps in each of 3 forested plots in Rock Creek Watershed.

⁴ Number of berries on 3 forested plots in Rock Creek Watershed. Includes *Arctostaphylos rubra*, *Cornus canadensis*, *Empetrum nigrum*, *Geocaulon lividum*, *Vaccinium uliginosum* and *V. vitis-idaea*.

⁵ Four off-road point count routes located in forested habitats in Rock Creek generate frequency of occurrence for passerine birds (see Paton and Pogson 1996).

⁶ Constant-effort mist netting at 3 stations in Rock Creek watershed, generates estimates of annual survivorship and productivity for passerine birds, as part of the Monitoring Avian Productivity and Survivorship program (see DeSante et al. 1995, DeSante 1997).

⁷ Mark-recapture trapping of small mammals on a plot in forested habitat in Rock Creek watershed generates an estimate of late summer population density (see Rexstad 1994).

Table 2: Description of avian, vegetation, and meteorological measures used in correlation analysis, Rock Creek Watershed, Denali National Park and Preserve, Alaska. See text for complete data description.

Measure	Description
WSI	Winter Severity Index
SOI	Spring Onset Index
SRI	Spring Rainfall Index
RICH (Pt. Cnt.)	Number of avian species identified from Point Counts
FO 5	Mean frequency of observation of 5 most observed avian species
FO 10	Mean frequency of observation of 10 most observed avian species
RICH (MAPS)	Number of avian species identified with MAPS
PROD 5	Mean productivity of 5 most observed avian species
PROD 10	Mean productivity of 10 most observed avian species
CPUE 5	Mean adult catch per 600 net-hours of 5 most observed avian species
CPUE 10	Mean adult catch per 600 net-hours of 10 most observed avian species
CONE	Total <i>Picea</i> cone count from 15 trees (5 trees in each of 3 forest plots)
SEED	Total <i>Picea</i> seed count in 18 traps (6 traps in each of 3 forest plots)
CROW	Total crowberry count in 6 berry plots (2 plots in each of 3 forest sites)
BLUE	Total blueberry count in 6 berry plots (2 plots in each of 3 forest sites)
CRAN	Total cranberry count in 6 berry plots (2 plots in each of 3 forest sites)
BERRIES	Total of all berries in 6 berry plots (2 plots in each of 3 forest sites)

Table 3. Correlation (r) of avian, vegetation, and weather variables with estimated *Microtus* and *Clethrionomys* abundance, 1992 - 1998, Rock Creek, Denali National Park and Preserve, Alaska. “Years” is the number of years of data available for each variable. P-value is for a test of the null hypothesis $\rho=0$.

Measure	Years	<i>Microtus</i>		<i>Clethrionomys</i>	
		r	P-value	r	P-value
WSI	7	0.83	0.02	0.56	0.19
SOI	7	0.44	0.33	-0.24	0.61
SRI	7	-0.22	0.64	-0.34	0.46
RICH (MAPS)	6	0.31	0.55	0.82	0.04
CONE	6	-0.26	0.62	-0.42	0.40
PROD 5	6	0.21	0.69	-0.25	0.62
PROD 10	6	0.86	0.03	0.49	0.32
CPUE 5	6	0.20	0.71	-0.74	0.10
CPUE 10	6	0.12	0.82	-0.62	0.19
RICH (Pt. Cnt.)	5	0.31	0.62	0.21	0.74
FO 5	5	-0.34	0.58	-0.61	0.27
FO 10	5	-0.35	0.57	-0.43	0.47
SEED	4	-0.07	0.93	-0.75	0.25
CROW	4	0.74	0.26	-0.12	0.88
BLUE	4	0.85	0.15	0.08	0.92
CRAN	4	0.62	0.38	0.66	0.34
BERRIES	4	0.81	0.19	0.08	0.92

Table 4. Correlation (r) of avian, vegetation, and weather variables with frequency of observation for 10 avian species in 5 migratory guilds, 1993 - 1997, Rock Creek, Denali National Park and Preserve, Alaska. P-value is in parentheses.

Measure	Residents	Irruptive Migrants	Short- Distance	Long- Distance	Neararctic Migrants
WSI	-0.07 (0.92)	-0.41 (0.50)	0.29 (0.63)	-0.46 (0.44)	0.17 (0.78)
SOI	0.72 (0.17)	-0.20 (0.75)	0.07 (0.92)	-0.42 (0.48)	0.19 (0.76)
SRI	-0.76 (0.13)	-0.69 (0.20)	0.59 (0.29)	0.75 (0.14)	0.68 (0.21)
RICH (MAPS)	0.17 (0.79)	0.40 (0.51)	0.12 (0.84)	-0.27 (0.66)	-0.14 (0.82)
CONE	0.85 (0.07)	0.46 (0.43)	-0.31 (0.61)	-0.02 (0.98)	-0.15 (0.81)
PROD 5	-0.59 (0.30)	-0.90 (0.04)	0.87 (0.06)	0.45 (0.45)	0.88 (0.05)
PROD 10	0.12 (0.85)	-0.37 (0.54)	0.20 (0.75)	-0.56 (0.33)	0.12 (0.85)
CPUE 5	0.61 (0.27)	-0.21 (0.73)	-0.11 (0.86)	-0.05 (0.94)	0.18 (0.77)
CPUE 10	0.50 (0.39)	-0.09 (0.89)	-0.42 (0.48)	-0.15 (0.80)	-0.12 (0.85)
RICH (Pt. Cnt.)	0.87 (0.06)	0.64 (0.24)	-0.82 (0.09)	-0.71 (0.18)	-0.75 (0.15)
FO 5	-0.35 (0.56)	-0.55 (0.34)	0.92 (0.03)	0.87 (0.05)	0.96 (0.01)
FO 10	-0.08 (0.90)	-0.22 (0.73)	0.85 (0.07)	0.81 (0.10)	0.83 (0.08)
SEED	-0.16 (0.84)	-0.63 (0.37)	0.97 (0.03)	0.73 (0.27)	0.98 (0.02)
CROW	0.90 (0.10)	-0.01 (0.99)	-0.62 (0.38)	-0.73 (0.27)	-0.42 (0.58)
BLUE	0.86 (0.14)	0.15 (0.85)	-0.65 (0.35)	-0.85 (0.15)	-0.51 (0.49)
CRAN	0.14 (0.86)	0.87 (0.13)	-0.84 (0.16)	-0.93 (0.07)	-0.95 (0.05)
BERRIES	0.82 (0.18)	0.21 (0.79)	-0.72 (0.28)	-0.86 (0.14)	-0.58 (0.42)

Table 5. Correlation (r) of avian, vegetation, and weather variables with productivity for 10 avian species in 5 migratory guilds, 1992 -1997, Rock Creek, Denali National Park and Preserve, Alaska. P-value is in parentheses.

Measure	Residents	Irruptive Migrants	Short- Distance	Long- Distance	Neararctic Migrants
WSI	0.82 (0.05)	0.38 (0.46)	-0.54 (0.27)	0.70 (0.12)	0.77 (0.07)
SOI	0.37 (0.47)	-0.40 (0.43)	-0.10 (0.85)	-0.20 (0.71)	0.35 (0.50)
SRI	-0.20 (0.70)	0.18 (0.73)	0.18 (0.73)	0.05 (0.92)	-0.39 (0.45)
RICH (MAPS)	0.17 (0.75)	0.40 (0.44)	-0.03 (0.96)	0.43 (0.39)	0.27 (0.60)
CONE	-0.38 (0.46)	-0.70 (0.12)	0.32 (0.54)	-0.63 (0.18)	-0.33 (0.52)
PROD 5	0.27 (0.61)	0.19 (0.72)	-0.07 (0.90)	0.41 (0.42)	0.04 (0.94)
PROD 10	0.78 (0.07)	0.69 (0.13)	-0.37 (0.47)	0.45 (0.37)	0.79 (0.06)
CPUE 5	0.06 (0.92)	-0.16 (0.76)	0.26 (0.62)	-0.76 (0.08)	0.05(0.93)
CPUE 10	0.06 (0.91)	-0.03 (0.95)	0.13 (0.81)	-0.72 (0.11)	0.10 (0.85)
RICH (Pt. Cnt.)	0.16 (0.80)	-0.13 (0.84)	-0.07 (0.91)	-0.45 (0.45)	0.39 (0.52)
FO 5	-0.40 (0.51)	0.19 (0.75)	0.59 (0.30)	-0.17 (0.78)	-0.59 (0.29)
FO 10	-0.52 (0.37)	0.49 (0.40)	0.79 (0.11)	-0.30 (0.63)	-0.63 (0.25)
SEED	-0.20 (0.80)	0.42 (0.58)	0.53 (0.47)	-0.22 (0.78)	-0.39 (0.61)
CROW	0.69 (0.31)	-0.33 (0.67)	-0.35 (0.65)	-0.38 (0.62)	0.70 (0.30)
BLUE	0.82 (0.18)	-0.23 (0.77)	-0.50 (0.50)	-0.19 (0.81)	0.83 (0.17)
CRAN	0.84 (0.16)	-0.22 (0.78)	-0.99 (0.01)	0.54 (0.46)	0.86 (0.14)
BERRIES	0.81 (0.19)	-0.30 (0.70)	-0.55 (0.45)	-0.18 (0.82)	0.83 (0.17)

Table 6. Correlation (r) of avian, vegetation, and weather variables with catch per unit effort for 10 avian species in 5 migratory guilds, 1992 - 1997, Rock Creek, Denali National Park and Preserve, Alaska. P-value is in parentheses.

Measure	Residents	Irruptive Migrants	Short- Distance	Long- Distance	Neararctic Migrants
WSI	0.35 (0.49)	0.06 (0.91)	-0.04 (0.94)	0.16 (0.76)	0.00 (1.00)
SOI	-0.34 (0.51)	0.52 (0.29)	0.40 (0.43)	0.20 (0.71)	-0.13 (0.81)
SRI	0.36 (0.48)	-0.06 (0.91)	-0.85 (0.03)	-0.73 (0.10)	-0.32 (0.53)
RICH (MAPS)	-0.23 (0.65)	-0.46 (0.35)	0.44 (0.38)	0.59 (0.22)	0.36 (0.48)
CONE	-0.62 (0.19)	0.21 (0.69)	0.47 (0.35)	0.28 (0.59)	-0.12 (0.83)
PROD 5	0.35 (0.50)	-0.01 (0.99)	-0.74 (0.09)	-0.46 (0.36)	-0.43 (0.39)
PROD 10	0.25 (0.64)	0.27 (0.60)	0.10 (0.85)	-0.14 (0.80)	0.36 (0.49)
CPUE 5	-0.36 (0.48)	0.89 (0.02)	0.26 (0.62)	-0.55 (0.25)	0.15 (0.78)
CPUE 10	-0.13 (0.81)	0.87 (0.02)	0.21 (0.70)	-0.62 (0.19)	0.26 (0.61)
RICH (Pt. Cnt.)	-0.36 (0.55)	0.48 (0.41)	0.88 (0.05)	0.34 (0.58)	0.79 (0.11)
FO 5	-0.25 (0.69)	-0.11 (0.86)	-0.52 (0.37)	-0.67 (0.22)	-0.38 (0.53)
FO 10	-0.58 (0.30)	-0.20 (0.75)	-0.16 (0.80)	-0.42 (0.48)	0.01 (0.99)
SEED	-0.32 (0.68)	0.29 (0.71)	-0.37 (0.63)	-0.83 (0.17)	-0.27 (0.73)
CROW	-0.11 (0.89)	0.93 (0.07)	0.87 (0.13)	-0.11 (0.89)	0.77 (0.23)
BLUE	0.00 (1.00)	0.84 (0.16)	0.90 (0.10)	0.09 (0.91)	0.75 (0.25)
CRAN	0.76 (0.24)	0.16 (0.84)	0.37 (0.63)	0.68 (0.32)	0.05 (0.95)
BERRIES	0.08 (0.92)	0.83 (0.17)	0.85 (0.15)	0.09 (0.91)	0.69 (0.31)

FIGURE CAPTION LIST

Figure 1: Denali National Park and Preserve, Alaska, showing the location of the Rock Creek watershed long-term ecological monitoring site.

Figure 2: 1992-1998 fall abundance estimates (animals/ha) for *Microtus* and *Clethrionomys* on RF1 plot, Rock Creek, Denali National Park and Preserve, Alaska.



